GREY BILLY AND ITS ASSOCIATES IN EASTERN AUSTRALIA

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[Accepted for publication 16th February 1972]

Synopsis

As a geological term " grey billy " was first used by David in 1887 to denote the quartzitic rock formed by the silicification of Tertiary sands and gravels under basalt, but its meaning has since been extended by some workers to include the siliceous duricrust. It is contended that to avoid confusion the name should be applied as originally defined.

The silicified rock is often ferruginous and may be variously coloured. It is found usually on the floors of old valleys, under basalt of older Tertiary (pre-Pliocene) age ; in frequent association with it are white (leached) bedded Tertiary clays, and leaching of the bedrock is not uncommon. Bedrock may be locally silicified. It is considered that the alterations—both silicification and leaching—have been effected by solutions related to the basalt, and that where the basalt has been entirely removed by erosion, the existence of any of the alterations indicates its former presence. Thus the grey billy association may be important in regard to palaeogeography.

Illustrative examples are described from various parts of New South Wales, particularly the Monaro country of the Southern Highlands, and the work of previous observers is reviewed. Brief mention is also made of the distribution of grey billy in the other States of eastern Australia.

INTRODUCTION

During the last century there have been occasional references, whose frequency has increased of late years, in the geological literature of the States of eastern Australia to sub-basaltic quartzites—Tertiary river- or lake-deposits that have suffered alteration through contact with superincumbent flows of basalt. The present paper is in part an attempt—by no means complete or exhaustive—to bring together and review references to described occurrences, and in part a record of my own observations made in the course of field-work over many years, particularly in the Southern Highlands of New South Wales.

My gratitude is due to Dr. J. A. Dulhunty, Prof. A. H. Voisey, Dr. F. W. Booker and Mr. D. G. Moye for kindly showing me relevant geology in the Goulburn River valley, parts of New England and the Central Highlands and the Adaminaby area respectively. My introduction to some of the occurrences in the Lower Hunter valley I owe to the late Sir Harold Raggatt, at the time an officer of the N.S.W. Geological Survey. Another member of that Survey, the late Mr. A. C. Lloyd, guided me to places of interest in the neighbourhood of Dubbo and elsewhere. Lastly I am much indebted to my wife for collaboration in the field, transport and discussion ; without her help much of the work could not have been done. For direction to outcrops of importance I have made considerable use of the excellent reports and reconnaissance geological maps of parts of the Southern Highlands made by members of the Geological Survey of N.S.W., and published in the 1950's. The topographical maps of the Adaminaby, Berridale and Dalgety areas made by the Snowy Mountains Hydroelectric Authority, of which copies were kindly made available to me, have proved extremely useful.

HISTORICAL

Silicified sub-basaltic deposits probably came under notice first in Victoria because much of the alluvial gold there occurred in what were known as " deep leads "—deposits of Miocene age or older that had been sealed down and preserved by flows of basalt. Hardening of the upper parts of the beds through siliceous cementation resulted in continuing protection after the disappearance of the basalt through erosion, and incidentally provided an obstacle to their economic exploitation. Other beds proved to be stanniferous in Queensland and New South Wales and for many years were significant producers ; now, however, they are chiefly of historic interest.

Mr. T. W. E. (afterwards Sir Edgeworth) David (1887*a*, 1887*b*), then on the staff of the Geological Survey of N.S.W., described from the Vegetable Creek (Emmaville) tin-leads of New England a hard, siliceous rock underlying basalt as " grey billy ", the name by which it was known to the local miners. So far as I am aware, this was the first definition of the term in geological literature, though the rock had already been referred to in earlier reports, and David himself had used the name without explanation in the Legend of a geological map (1884). It seems to have been originally applied to bouldery masses of quartzitic rock which were probably for the most part formed by disintegration and weathering *in situ* of sheets of the material, but David also referred to " irregular-shaped lumps of hard rock 2 to 3 feet in longest diameter " through which current-bedding of the surrounding loose drift could often be traced ; he suggested that these " concretions " were formed by segregation of silica in the uncompacted deposits. The sub-basaltic quartzite was called " flinty quartzite " by Brown (1926) and " contact quartzite " by Craft (1931*a*).

In his interesting book on opal the late F. G. Leechman (1961), himself a Cornishman, stated that " billy " is a corruption of " bully ", a common Cornish term for " a big, round stone " ; since many of the original tin-miners in New England came from Cornwall, this is without doubt the correct explanation of the word, the adjective being obviously an allusion to the prevailing colour of the rock.

B. Dunstan (1900, 1902*a*) of the Geological Survey of Queensland, who had received his geological training in New South Wales, gave the name " billy " to rounded siliceous boulders appearing in river-alluvium in the Clermont area, and later to similar boulders associated with alluvial sapphires in the neighbouring Anakie field (1902*b*). Perusal of his reports suggests that he was referring to two similar-appearing rock-types with very different origins, some apparently of sub-basaltic type, others disintegrated siliceous duricrust (Woolnough, 1927). According to Whitehouse (1940, p. 4), after it had been shown that some quartzitic rocks were due to metamorphism by Tertiary basalt Dunstan suggested a similar origin for the duricrustal quartzites of western Queensland ; Whitehouse also (p. 13) states that the name " billy " has been used in Queensland for the two types of quartzitic rock indifferently. Discoveries of precious opal in association with duricrust popularized the use of " billy " for duricrustal quartzite in Queensland, and this usage spread to New South Wales (cf. Kenny, 1934 ; Whiting and Relph, 1961 ; Branagan, 1969) though it appears not to have reached South Australia, the other opal State.

To denote siliceous surface-crusts of uncertain origin found in South Africa Lamplugh (1907) coined the word " silcrete ". These crusts appear to be somewhat analogous to certain surface-quartzites of western Queensland. The term was first applied to Australian duricrustal quartzite by Williamson (1957), but, unfortunately, its meaning has been by some writers (e.g. Vallance, 1969, p. 525) extended to include the sub-basaltic rock. Others, like Voisey (1942*a*, 1942*b*) and the authors of the Geological Survey reports on the Snowy Mts., Adamson, Hall and Lloyd (1954, 1955, 1956) employ the term " grey billy " exclusively in describing the sub-basaltic deposits ; while Chalmers (1967) equates " grey billy " and " silcrete " and deprecates the use of the former for silicified sub-basaltic deposits. Since the formations in question are genetically different, but each in its own way is significant in regard to the Kainozoic history of Australia, it is desirable for the avoiding of confusion that a clear distinction be drawn between them by strict use of appropriate designations. Some of the rather heterogeneous quartzites so widespread in the interior of the continent are possibly to be grouped with silcrete, but the name " grey billy " clearly has priority, and should be used, for the sub-basaltic rocks which are the subject of this note.

General Description of Grey Billy

Though originally denoting large rounded boulders, the name is now applied more particularly to the layers or sheets of silicified sand and/or gravel often occurring beneath terrestrial Tertiary basalt-flows and as a designation for specimens of this material. A specific colour is not implied by the name any more than it is by " greywacke ", but certainly by far the commonest colour is pale grey, though it may be pink, cream, yellow, yellow-brown, dark red, dark brown, bluish, black or white. For the most part the original materials have been valley-floor and perhaps lake-shore deposits, but where there has been valley-in-valley structure silicified terrace-deposits resting upon bedrock may be seen at levels well above that of the innermost valley-floor. Raggatt (Browne and Raggatt, 1935 ; Raggatt, 1939) described such from Trunkey in the Central Highlands.

Probably most grey billy occurs in old river-valleys, but where the basalt was poured out on a plateau-surface the regolith covering it may show silicification. Cotton (1910) described from Elsmore and other places in western New England outcrops of silicified granite debris, chiefly of coarse angular quartz-grains with large lumps of stanniferous reef-quartz scattered through it ; and Voisey (1942) has recorded fossil granite soils converted into grey billy in the Uralla area. In the Central Highlands some 9 miles east of Crookwell on the plateau-surface about 3,000 feet ASL grey billy has been noted consisting of angular fragments up to 9 inches long of granitic material embedded in a matrix of coarse, angular quartz-grains.

Plant-remains have occasionally been found in grey billy. The well-known occurrence in the township of Dalton in the Yass district (Sussmilch, 1937) contains abundant distinct plant-impressions, the original material having possibly been carbonized by heat and later etched out by weathering. Fragments of charcoal, silicified roots and stems of a fossil angiosperm have been reported from grey billy near Ulladulla on the South Coast (Brown, 1926) and hollow casts of plant-stems from silicified soil 10 miles north of Armidale (Voisey, 1942*b*) ; the material containing them may have been silicified clay rather than sand. David (1887*b*) and Curran (1891) found blocks of silicified wood in the grey billy of Emmaville and of Bald Hills (Mt. Panorama) near Bathurst respectively. Plant-remains, however, are perhaps more common in the unaltered beds beneath the grey billy.

The layer of grey billy may be up to 8 or 10 or even 15 feet thick but may thin out laterally and is often succeeded downwards quite sharply by uncompacted gravel, sand, clay or other material.

Where the basalt has been eroded away and the deposit beneath it revealed, the grey billy may weather into angular blocks of about 6 or 8 inches edge which are strewn over the ground where the basalt has been. More commonly, however, the silicified layer tends to be undermined and cracked, and eventually to break off in isolated large blocks or tabular masses with rounded and generally smooth, dimpled surfaces and a lustre varying from subvitreous to dull according to grainsize and degree of cementation. These masses may in time become partially buried in the loose gravels originally beneath them or in others of a later generation, and no obvious evidence of a continuous sheet may exist, but the size, shape and abundance of the blocks or slabs will serve as a proof that they are virtually *in situ* ; in certain instances a train of isolated boulders may be traced to the mass whence they were derived.

If silicification has been incomplete or unevenly distributed differential weathering makes the rock irregularly cavernous ; individual sand-grains are etched out, particularly where the cement is in part ferruginous, and if the rock has been gravelly pebbles may be completely weathered out.

Texture and Composition

The sandy grey billy has very variable grainsize ; it may be exceedingly fine-grained and compact, almost glassy and with a smooth fracture and greasy or oily lustre, but is more usually medium-grained or coarse and gritty with subordinate matrix, saccharoidal texture and uneven fracture. Another type consists of little glassy quartz-grains and tiny rock chips sporadically distributed through an irresolvable or felsitic matrix ; it has a stony or porcellanous appearance and an almost conchoidal fracture. Much of the Hunter valley material is of this type (Raggatt, 1939). Some types composed entirely of exceedingly fine irresolvable material may be silicified clay or soil. Silicification appears to have been the result of deposition from solution, producing cementation and metasomatism. Where a rudaceous layer is interbedded individual pebbles may be replaced by silica with retention of original structures such as bedding (Browne, 1964). Many pebbles are of white vein-quartz which has been immune from metasomatism, but their boundaries against the matrix are occasionally blurred by secondary outgrowths (Murray, 1887 ; Dunstan, 1900*b*). In the coarse sandy type outgrowths in optical continuity may give the grains a hexagonal outline perceptible by the naked eye. Commonly massive, the rock may show bedding or layering, through the inclusion of pebbles, and is occasionally cross-bedded. Very rarely it may be intersected by quartz-veinlets.

Little is known of the microscopic petrography of grey billy. David considered the cementing material of the Emmaville grey billy to be chalcedony. Specimens of the Ulladulla rock (Brown, 1926) consist of allothigenic quartz in a cryptocrystalline matrix and contain more than 98% of silica. Compact types from Tallong (Waterhouse and Browne, 1930) show common opal both as a matrix and as paper-thin veinlets associated with chalcedony, but in other types quartz is the sole siliceous constituent. Some specimens are composed of discrete angular quartz-grains with corroded edges in a microcrystalline matrix. Williamson (1957) briefly described samples from various parts of New South Wales and Victoria and made the interesting discovery of clusters of minute rutile prisms associated with authigenic quartz in samples from Tallong ; the titanium, he suggested, might have " entered into solution from the overlying basalts ". Analysed samples of the Tallong and other New South Wales rocks yielded Williamson silica-percentages by weight between 97 and 99, with very small percentages of other constituents, iron oxides reaching a maximum of 2·18 and TiO_2 of 1·27.

In the grey billy of New England alluvial gold and stream-tin were found, sometimes in quantities sufficient to warrant extraction, and it is likely that topaz, sapphire, garnet, zircon and other detrital minerals are present, as they are in the unconsolidated gravels and sands.

Selective Alteration

Not everywhere, even in the same valley, is the contact between basalt and underlying sediments marked by grey billy ; indeed, in some instances there is little or no sign of alteration. Two basalt-flows may be separated by a layer of dark red-brown bole, a partially consolidated substance that adheres to the tongue, really a soil derived from the lower flow and altered by the upper. At Tallong at a spot where basalt has rested directly on fine-grained Permian sandstone, this is prismatized and somewhat hardened but otherwise apparently unaltered. To the left of the road between Yarrangobilly Caves and the village of Yarrangobilly, some 12 miles north of Kiandra, are four thin flows of basalt with small thicknesses of interflow and subflow sediments ; those beneath the upper flows are uncemented grits, but the lowest flow is underlain by grey billy resting on bedrock of partly silicified limestone. The reason for this selectivity is not clear.

Relation to Basalt

David stressed the situation of the Emmaville grey billy at the contact between basalt and gravels, and other workers have done likewise. Most of the outcrops I have seen are either in evident contact with overlying basalt or are traceable laterally with little or no interruption into material that does underlie basalt, so that the relation to the volcanic rock is abundantly clear. In other instances the grey billy is separated by a few miles from the nearest basalt outcrop, but generally the distribution of basalt remnants great or small indicates sufficiently their former continuity across the intervening space. These relations are well exemplified in the Shoalhaven country, for which Craft's (1931*a*, 1931*b*, 1931*c*, 1932*a*, 1932*b*) maps and descriptions make quite evident the close relation of his " contact-quartzites " to Tertiary basalt-flows ; a particularly clear instance is exposed near Badgery's Lookdown at Tallong. Even where no basalt is known to occur for miles around, the physical characters of the rock itself and its relation to its environment are usually sufficient for identification.

The suggestion is occasionally made that even where there is actual contact the relation of billy to basalt is purely adventitious, that it is the remnant of a pre-basaltic crust of unspecified antecedents that has had the good fortune to be preserved in a hollow under basalt ; its occasional long distance from known basalt outcrops is considered to support this hypothesis. To those holding such views the classic advice " Go and see " cannot be improved upon. He would indeed be a very timid or very obstinate fellow who could retain any vestige of doubt of a causal relation after extended examination of the field-evidences—the oft-repeated close and intimate association of grey billy and basalt, the silicification of screes and soils and terrace-deposits as well as valley-floor sediments in the vicinity of basalt-flows, the silicification of interflow deposits and the association of both basalt and grey billy with underlying leached beds, as noted below.

Associated Sub-basaltic Deposits

In natural exposures or in artificial excavations like quarries and road-cuttings it is sometimes possible to get partial or complete sections through grey billy and the deposits beneath it down to their base and into bedrock. Where the original material was gravel or boulders the silicified layer may be underlain by loose gravels. But the valley may have been very mature and its deposits may have included flood-plain silts, or it may have for some reason expanded locally into a lake with clayey and fine sandy sediments showing bedding, lamination, cross-bedding and contemporaneous washouts, perhaps with occasional layers of peat or lignite. The clay is commonly white, cream or pink, and is locally known as pipeclay ; it may be associated with grey billy or may directly underlie basalt. So far as I know it has always been tacitly regarded as a normal transported deposit. It is true, of course, that white clay may, in association with carbonaceous beds or in certain climatic and/or topographical environments, such as those characteristic of the far North Coast of New South Wales, result from the decomposition *in situ* of basalt and other rocks, and that this material may be eroded, transported and deposited in still waters. But the close and common association of the clays here referred to with basalt suggests very strongly that they are related to it and have been leached after deposition, probably by magmatic waters. It would appear that leaching may be selective and diminishes at depth in the deposits. Occasional lenses or layers of very fine white and even running sands are found amid the clay, and the clayey matrix of compacted gravel beds is apt to be leached.

Sub-basaltic white clays are almost ubiquitous in association with the Tertiary basalts of this State. David found them at Emmaville, locally prismatized in contact with basalt, and they have been noted in various parts of the Central Highlands. Craft reported white clays and sands from the Shoalhaven country and they are very common, either under grey billy or directly under basalt, in other parts of the Southern Highlands, as in the Cooma-Adaminaby-Berridale-Dalgety area and at Bombala (Relph, 1969). In my experience the beds do not as a rule exceed 25 feet in thickness, but from the succession given by Gill and Sharp (1957, pp. 29–30) it would appear that at Kiandra leaching has persisted, somewhat selectively, through a depth of about 80 feet from the base of the basalt. One circumstance, the significance of which has not been satisfactorily explained, is the frequency with which at the base of the sub-basaltic column white clay is found resting on leached bedrock and overlain by gravelly or sandy deposits.

Limonitic material under lava-flows has been noted in a few places, as in the Comboyne plateau on the middle North Coast, where it appears as a finely laminated bed about 8 inches thick possibly deposited rhythmically, or seasonally, as a cement to detrital sands or gravels ; in such circumstances it is explicable as having been precipitated from springs on the bed of a pre-basalt lake or river. But quite frequently the siliceous grey billy is coloured a dark brown, apparently through deposition of thin films of iron hydroxide, and indeed in certain places this seems to be the sole cementing material. Its time-relation to the silicification has not been investigated, but its close association with the grey billy suggests contemporaneity.

Carbonaceous beds close to the basalt-contact may be changed into a coaly substance—a case of simple heat-metamorphism ; such an occurrence was briefly referred to by Dulhunty (1946) from Cottage Creek some 16 miles south of Cooma. Diatomaceous earth deposits may be locally converted into common opal, as at Bunyan near Cooma and Wyralla and Tintenbar on the Richmond River (Morrison, 1920).

A comparatively rare associate of grey billy is travertine or kunkar. David (1887*b*) and Cotton (1910) both reported it with basalt and grey billy from a number of places in New England, and an occurrence from Rock Flat near Cooma is mentioned below. It is not clear whether the travertine is related to the grey billy or whether the association is purely fortuitous. Though travertine is deposited from hot springs in volcanic regions, the similar substance *kunkar* is known to result sometimes from the weathering and decomposition of basalt, forming discrete nodules or continuous sheets in basaltic soil.

Bedrock Alteration

Leaching has not been confined to the sub-basaltic sediments but has also quite frequently affected bedrock to a depth of several feet, producing white clay (pipeclay). Slates, particularly where highly jointed and steeply dipping, seem to be very susceptible to attack by percolating waters, but biotite-granite on which basalt has been outpoured has been reduced to an incoherent and barely recognizable mass of white clay and sand. Leaching of slates, which has been studied chiefly in the Central and Southern Highlands, appears to be in some way selective, leached being side by side with quite unleached sections of the bedrock, possibly as the result of varying permeability.

On the other hand certain phenomena suggest selective sub-basaltic silicification of bedrock. Of the examples observed the most interesting is that of Rock Flat, 2,900 feet ASL, 9 miles from Cooma on the road to

Nimmitabel ; this occurs in the broad valley of Rock Flat Creek, formerly basalt-filled but now locally eroded down to bedrock. Unfortunately, the silicified outcrops have been much mutilated by quarrying, but originally there were a larger and a smaller mass rising from the alluvium of the creek along a roughly meridional line. At the northern end of the smaller is a bubbling " soda-spring " and from the creek-bank near by a chalybeate spring issues (cf. Pittman, 1901) ; these, with other small springs now extinct, have been responsible for a terrace or platform of ferruginous travertine a few feet above the creek (Browne, 1914). The larger siliceous outcrop shows lamination dipping steeply, and quarrying revealed pockets of loose quartz-sand amid the solid rock well below the surface, suggesting a shaly sandstone that had been imperfectly silicified and later disintegrated by percolating surface-water. The smaller outcrop is massive, but intersected by a cemented breccia of angular quartzite blocks resembling closely the fault-breccias found in some Palaeozoic limestones. In one of the masses ripple-marking was noted. The rock is typically opaque white, very pure, fine and even-grained, and the internal evidence and general environment suggest that the outcrops are remnants of sandstone, shale and perhaps limestone that had protruded from the pre-basalt valley and had been metasomatically altered by a basalt-flow. A few hundred yards away to the west a belt of Silurian quartzite that emerges from beneath the cover of Tertiary basalt and crosses the railway line obliquely near Rock Flat siding is locally converted into what appears to be chalcedonic silica. Craft (1931*b*, p. 251) has noted the local conversion of Palaeozoic sandstone into glassy " contact-quartzite " under Tertiary basalt at Windellama in the Shoalhaven country.

In a different catagory is a mass of vein-quartz standing in the midst of grey billy at Kings Plains near Blayney, apparently a resistant Palaeozoic relic around which pre-basalt Tertiary sediments were deposited. A similar occurrence has been described by McRoberts (1948) from Bombala.

Source of the Solutions

There can be little doubt that the solutions responsible for the changes in the original deposits were somehow connected with the basalts, but the nature of the connexion is a matter of speculation. For grey billy the problem was briefly discussed by Waterhouse and Browne (1930) and by Williamson (1957). The geochemistry of the process of alteration is beyond the scope of this note, but attention may be drawn to the following considerations :

1. The great majority of the basalts concerned are of alkaline type and many of them show signs of deuteric alteration involving late-magmatic solutions. In particular, in the Southern Highlands they are known to include examples of " sunburnt basalt " (Lafeber, 1956), notable for its content of analcime and other zeolitic minerals and likely to be accompanied by alkaline solutions ;
2. Sub-basaltic silicification and leaching are not constant or universal, but selective ;
3. Any explanation must account both for grey billy, in which alteration has been essentially constructive or additive, and for leaching, in which it is destructive or subtractive.

Order of Deposition

The common appearance of terracing or trap-featuring in the Tertiary basalts indicates that there has been repeated outpouring of flows with a time-interval between them sufficient to permit consolidation of the rock, weathering and soil-formation on a given flow or even the deposition on it of gravels, sands or finer alluvia. That the time-interval has not always been regular is suggested by the fact that the thickness of interflow sediments is very variable.

From the alternation of flows and alluvial deposits in a valley the natural inference is that the valley was repeatedly shallowed and the valley-floor raised, perhaps with ponding of the stream by a basalt barrier, until the valley was completely filled. Obviously the higher deposits and flows are the younger.

Occasionally, however, one finds evidence of what seems to have been valley-in-valley structure, where alluvial deposits appear on bedrock terraces or shoulders on the valley-sides at one or more levels well above its floor, and all the deposits have been buried beneath basalt. It may be difficult to determine the sequence of events in such circumstances. There may have been true valley-in-valley structure with remnants of earlier alluvium on the upper valley-floor and a succession of basalt-flows may have buried both the earlier and the later deposits ; in this case the highest alluvium is the oldest and the higher basalt the youngest. On the other hand, an appearance of terraces and terrace-deposits may have come about if, during an interval in the normal filling of the valley by successive flows, there was erosional encroachment on the valley walls, with later deposition on the newly excavated bench before the next flow. In this event both the highest basalt and the highest alluvium are the youngest.

The orderly succession of events may, of course, have been interrupted by tectonic movements or by the formation, at some stage, of twin-streams (Browne and Raggatt, 1935).

Geological Age of Grey Billy and its Associates

In general it may be said that the Tertiary basalts in eastern Australia with which the altered sub-basaltic sediments are connected form part of the erosion-surface of the Miocene peneplain, occupy exhumed valleys sunk below its surface, or, more rarely, are perched on monadnocks upon it. Recent isotopic datings—certainly not numerous as yet—suggest that the volcanic activity spanned a time-range from Lower Eocene to Miocene (Dulhunty and McDougall, 1966 ; McDougall and Wilkinson, 1967 ; Webb *et al.*, 1967 ; Wellman *et al.*, 1969) in New South Wales and south-eastern Queensland, the majority of the samples so far tested being Lower Miocene or Oligocene. This period of extrusion corresponds approximately with that postulated for the Older basalts of Victoria, and in these notes is for convenience designated earlier Tertiary. For eastern Victoria Murray (1887) noted that silicified Tertiary alluvium is connected with the Older basalts, and Gill (1942) reported it from under Older basalt at Lilydale. On the other hand a detailed account of the Kainozoic sediments associated with the Newer basalts of western Victoria by Gill (1964) makes no mention of silicified deposits, and a similar significant silence is noticed in Murray's account of the Newer basalts. Many years ago Dr. D. E. Thomas, former Government Geologist of Victoria, told me that in his experience silicification of sub-basaltic sediments is known only in connexion with Older basalts. The only apparent exception is at Mt. Macedon where Skeats and Summers (1912) stated that sands and gravels under Tertiary trachytes and Newer basalt are locally changed to quartzite.

During a short visit to the country some 50 miles east and north-east of Hughenden in northern Queensland I had an opportunity of examining flat-topped and slightly dissected plateaux covered with what are probably Newer (late Pliocene and Quaternary) basalts (*cf.* Maitland, 1898). Though occasional subflow and interflow deposits were noted I saw no signs of sub-basaltic silicification or leaching. This negative evidence, of course, may or may not be significant.

It has generally been assumed that extrusion of the basalts followed closely on deposition of the sediments (Andrews, 1914, pp. 519–520 ; Sussmilch, 1937 ; Voisey, 1957 ; Gill and Sharp, 1957). This, indeed, might well be inferred from the common occurrence of interflow deposits, the occasional presence of amygdaloidal phases at the base of the basalt, the corrugation or crumpling of apparently still plastic clays by the " push " of advancing lava and the local leaching of sediments, which would be accomplished more readily in relatively loose and permeable than in compacted deposits. Unfortunately, discrepancies have been found between age-determinations of beds and basalt made by different methods. For example, the plant-bearing beds at Armidale (Voisey, 1957) were on palynological grounds thought to be Eocene or early Oligocene, but by isotopic dating (McDougall and Wilkinson, 1967) the basalt covering them is late Lower Miocene (21 m.y.). If one is to regard both methods of determination as reliable, then, to reconcile the conflicting dates one must assume that an interval of 10 m.y. or more separated deposition and burial of the beds. Such an explanation is rendered somewhat less improbable by Slade's discovery, quoted by Voisey, that the Armidale beds had been dissected to a depth of 200 feet before extrusion of the basalt.

In a somewhat different category is the diatomaceous earth at Bugaldi in the Warrumbungle Mts. area, which contains skeletons of the fossil fish *Maccullochella macquariensis* (Murray Cod) ; these Hills (1946) considered to be not older than Pliocene, but the olivine-basalt on top of the beds is apparently equivalent to that which has been dated (Dulhunty and McDougall, 1966) as Upper Miocene. At Bunyan near Cooma, where an identical skeleton was found, the enclosing diatomaceous earth is older than the basalt hard by, which itself is older than the Miocene peneplain.

It would be interesting to compare a K/Ar dating of the basalt at Kiandra with the age of the underlying lignite, determined on its pollen-content as Upper Eocene or Lower Oligocene (Gill and Sharp, 1957) ; and an isotopic age for the basalt in the Redbank Plains beds of the Brisbane-Ipswich area in Queensland (Jones, 1926) with that based on the fauna of the associated sediments—probably Eocene or Oligocene (Hills, 1934).

Post-Basaltic Deposits

Though not necessarily related directly to the sub-basaltic beds, certain post-basalt deposits are not uncommonly found in close proximity to them. Erosion induced or accelerated by the late Miocene (?) Macleay uplift (Browne, 1967) caused older Tertiary basalt-filled valleys to be exhumed in many instances down to approximately their pre-basalt bed-level, exposing their original sediments, often silicified ; these were then broken up and redistributed among the deposits of a later period. Many very mature upland valleys and valley-plains of the plateau areas of New South Wales as we see them now are demonstrably post-basalt and pre-Kosciusko uplift and may reasonably be referred to an earlier Pliocene stillstand that followed the Macleay uplift ; a closer look will show that many if not all of them are really re-excavated pre-basalt valleys and contain relics of their original alluvial deposits. Where these have been gravels or sands that have remained uncemented, differentiation between the old and the new may be difficult or impossible, but where a layer of grey billy was formed this was in many instances undermined and broken into fragments which became more or less rounded and waterworn and incorporated as cobbles or boulders in the Pliocene deposits. These may also contain pebbles of basalt and redistributed material from loose pre-basalt deposits. The size, abundance and degree of rounding of the grey billy boulders may provide a rough guide to the distance of transport from their original situation and they may even be traceable laterally into almost undisturbed remnants of silicified rock *in situ*. These relations of pre-basalt and post-basalt deposits are well exemplified along the Upper Murrumbidgee near Adaminaby, the Shoalhaven down to Tallong and the Lower Hunter, as noted below.

Due to erosion since the long Pliocene stillstand some of the post-basalt accumulations have suffered dissection, so that remnants of them are " perched " with respect to a later valley floor. However, gravels and boulder-deposits in these upland valleys are being added to at the present day as, for example, where the still eroding tributaries of a main mature valley debouch on to its floor. Such accumulations, in the form of fan-deposits containing in some instances cobbles and boulders of grey billy, are to be seen in tributaries of the Snowy system in the Berridale-Dalgety area.

The great uplifts of the Kosciusko epoch induced considerable rejuvenation of the earlier Pliocene rivers, from the coast far into the highlands on the east, and from the hinge of uplift on the west, so that both pre-basalt and earlier-Pliocene deposits are now high above existing river beds in the rejuvenated sections as, for example, in the Lower Shoalhaven and in many Upper Macleay tributaries.

The Vanished Basalt

Tertiary basalt attains quite considerable thicknesses in the Eastern Highlands of New South Wales. Probably the thickest pile is that forming the Liverpool Range just north of the Goulburn River, which measures upwards of 2,500 feet. At Point Lookout, 50 miles east of Armidale, the basalt is 1,500 feet thick (Andrews, 1904) and that of the Mt. Royal Range probably exceeds 1,000 feet. In the Southern Highlands 15 miles south of Cooma Hudson's Peak is 4,042 feet ASL, and from its top to the neighbouring Rock Flat Creek there is a thickness of about 1,100 feet of basalt, while at The Three Brothers 10 miles south of Cooma the basalt is more than 800 feet thick. Elsewhere the flows have been reduced to remnants less than 100 feet thick, may be represented only by thin spreads of boulders, or may have disappeared completely. An inspection of the State Geological Map or of larger-scale maps of regions in the Eastern Highlands belt reinforces the impression gained from field study that the basalt-cover was formerly of very much greater vertical and lateral extent. If account is taken of the relics of grey billy and/or its associates cropping out far from any basalt, and of basaltic dykes of probable Tertiary age, the area is materially increased.

Removal of large volumes of basalt without leaving a trace is not altogether surprising. The rock-mass carries within itself the elements of its own destruction, since the deuteric alteration to which it is so subject causes the parts affected to decompose readily in the belt of weathering. The " sunburnt basalt ", not uncommon in the Cooma-Dalgety-Kiandra area and recognizable by its hackly fracture, is prone to disintegration at the surface into small angular and pisolite-like fragments which are readily transported (they have accumulated abundantly, for instance, around Maffra Lake and elsewhere), and the layers of palagonitic material amid the basalt are subject to chemical breakdown. Moreover, the volcanic mass, especially in valleys, often consists of a series of relatively thin flows, each perhaps 20 or 30 feet thick, in some instances columnar, and separated by interflow soils or sediments which, besides being liable to erosion, may act as channels for groundwater. For these and other reasons decay, disintegration and removal of basalt is apt to be comparatively rapid.

Duricrust and the Grey Billy Association

In general grey billy and its associates are easily recognized, particularly where Tertiary basalt is in an appropriate position near by, but there may be circumstances in which uncertainty arises.

The lateritic duricrust profile consists typically of three main elements (Whitehouse, 1940), in descending order the ferruginous or lateritic, the mottled, and the pallid or kaolinic zone. In western Queensland Whitehouse found a discontinuous or lenticular siliceous layer to be occasionally present, perhaps most commonly in the mottled zone. Except for the siliceous layer the succession, so far as is known, holds with a varying degree of completeness for the Eastern Highlands belt of New South Wales but, mainly beyond the Darling River, a siliceous zone appears at the top, followed downwards by a soft pallid zone. Woolnough (1927) seems to have equated this siliceous zone to the laterite of eastern Australia, but at the time he wrote very little was known about laterite in the east—although David (1887*b*, 1889) had already reported and described laterite from Emmaville—and very little interest was taken in it or its genesis. Investigations made since Woolnough wrote (e.g. Kenny, 1934 ; Wöpfner, 1960, 1961) have cast doubt on the correlation, and shown that the so-called siliceous zone is rather more complex than he envisaged and may include components of more than one geological age and origin. Moreover, lateritic and lateritoid materials have become known which lie in broad upland valleys of probable earlier-Pliocene age and are therefore younger than the duricrust.

In New South Wales a distinction can generally be made between the duricrust profile and the grey billy association. The former rests on the Miocene peneplain surface, some of it, indeed, derived from the basalt of which that surface is partly composed. On the other hand, grey billy and its associates are broadly contemporaneous with or somewhat older than the basalts and crop out on top of the volcanic rock only where the overlying flow responsible for the alteration has vanished through erosion ; they commonly bear no close relation to the Miocene peneplain surface, occurring as a rule either in valleys cut into it or on monadnocks above it.

Where, as often happens, parts of the duricrust profile or of the sub-basaltic succession are missing distinction may be difficult. There may be similarities in appearance and weathering pattern between sandy grey billy and the siliceous duricrust of the far west and north-west of the State, but for the former the not uncommon association of pebbly layers, the pebbles usually well sorted, well rounded and obviously alluvial, should provide a fairly reliable criterion of origin. The mottled zone of the duricrust has no counterpart in the grey billy association, but leached sub-basaltic clay, whether derived from contemporaneous alluvium or from bedrock, may easily be mistaken for the pallid zone of the duricrust, particularly where the top part is iron-stained, simulating a mottled zone. In such circumstances the relation to the Miocene peneplain surface and the general topographical and lithological surroundings may help to resolve the difficulty. For instance, the deposit of finely-laminated white clay underlain by white sand near Dalton in the Yass-Gunning area is not far from the grey billy in a wide upland valley at Dalton village, and the hills a few miles away are capped with Tertiary basalt (Morrison and Raggatt, 1928, p. 218 ; Sussmilch, 1937 ; Joklik, 1950). Again, the transported white clay described by Morrison and Raggatt (1928, p. 219) from Home Rule near Gulgong, more than 14 feet thick and buried under 45 feet of quartz-gravel and sandy alluvium, is in an area of Tertiary deep leads overlain by basalt largely covered by surface-alluvium. Both these deposits are more likely to be of sub-basaltic than of duricrustal origin.

It is true that remnants of a grey billy association and of duricrust, both *in situ*, may be quite close together, as in the Emmaville and Inverell districts of New England and on the Shoalhaven Plain, and that for individual outcrops distinction may be far from easy ; however, if basalt is present, the spatial relation of the doubtful outcrop to it, if determinable, should be conclusive. Of course, in rare instances erosion and river transport may have brought about a mingling of grey billy boulders and disintegrated siliceous duricrust, as appears to have happened at Clermont and Anakie in Queensland (Dunstan, 1900, 1902), in which case distinction by field methods may be quite impossible.

Very little laboratory research appears to have been done on the siliceous zone of the duricrust, apart from that by Williamson (1957). It might be possible to establish mineralogical criteria to supplement the results of field study in distinguishing between it and grey billy; for example, one might expect chalcedony and/or common opal to play a prominent part in the cementing material of duricrustal quartzite in contrast to the predominant role of authigenic quartz in grey billy. White clay from the pallid zone of a siliceous duricrust has yielded 30% of free silica, expressed largely as opaline cement and replacement of felspar in an originally arkosic rock; but it is doubtful if any reliable mineralogical or chemical distinction is possible between the sub-basaltic clay of the Eastern Highlands belt and the pallid-zone clay of the lateritic duricrust, which is the type prevalent in the same belt.

The Grey Billy Association in New South Wales

General

Grey billy and some of its associates are widely distributed in the Eastern Highlands belt of this State. They are known from Bombala on the south (McRoberts, 1948) to Emmaville on the north (David, 1887) and from Ulladulla and Narooma on the east (Brown, 1926; Hall, 1969, p. 555) to Condobolin and Cargelligo (Raggatt, 1938) on the west. In conjunction with relics of Tertiary basalt they help to throw light on Kainozoic palaeogeography and on topographical history. Apart from mention made above, it is proposed to illustrate this thesis by giving notes on specific examples and considering some of their implications. Most attention is devoted to the Monaro country of the Southern Highlands, with which I am familiar and which has been mapped by the State Geological Survey and by myself. It is covered on a scale of 1 : 100,000 by Commonwealth Military Topographic Sheets 8725 (Cooma), 8625 (Berridale), 8626 (Tantangara) and 8624 (Numbla), and is included in less detail in the General Map of the Snowy Mountains Area (1 : 250,000) published by the Snowy Mountains Hydroelectric Authority, on which Fig. 1 is based. Geological maps accompany the appropriate Geological Survey reports, but on them no distinction is made between earlier and later Tertiary rocks. Other areas mentioned herein I have studied in much less detail. Where possible the occurrences are grouped according to the river-systems with which they are associated. Altitudes are based on reduced aneroid readings and are approximate.

Eucumbene-Snowy Basin

Kiandra.—Andrews (1901) noted white clays with interbedded lignites directly under basalt at New Chum Hill, and elsewhere found scattered large blocks of grey billy derived from an adjacent sub-basaltic source. These are within the walls of the wide Eucumbene valley near its head, and perhaps 200 feet above its present floor at Kiandra. Other basalt-capped outcrops of grey billy south and south-west of Kiandra within the Tumut River valley (Hall and Lloyd, 1954) belong to the Murrumbidgee system.

Adaminaby Plateau.—This is crossed from NW to SE by the Main Divide and its western part is drained by Eucumbene tributaries (Fig. 1). Adamson (1955) found several small patches of basalt on the valley walls and floor of Fryingpan and Buckenderra Creeks (now both incorporated in Lake Eucumbene reservoir up to 3,800 feet ASL) at altitudes ranging from 3,800 to 4,000 feet, and the western wall of Buckenderra valley is a ridge rising to 4,400 feet, capped with basalt 300 feet thick. In a few places this rests on alluvium, the highest known at 4,120 feet, near the northern end of the ridge. No sign of alteration has been noted, but Pipeclay Creek, basalt-filled near its source at 4,200 feet, is suggestively named.

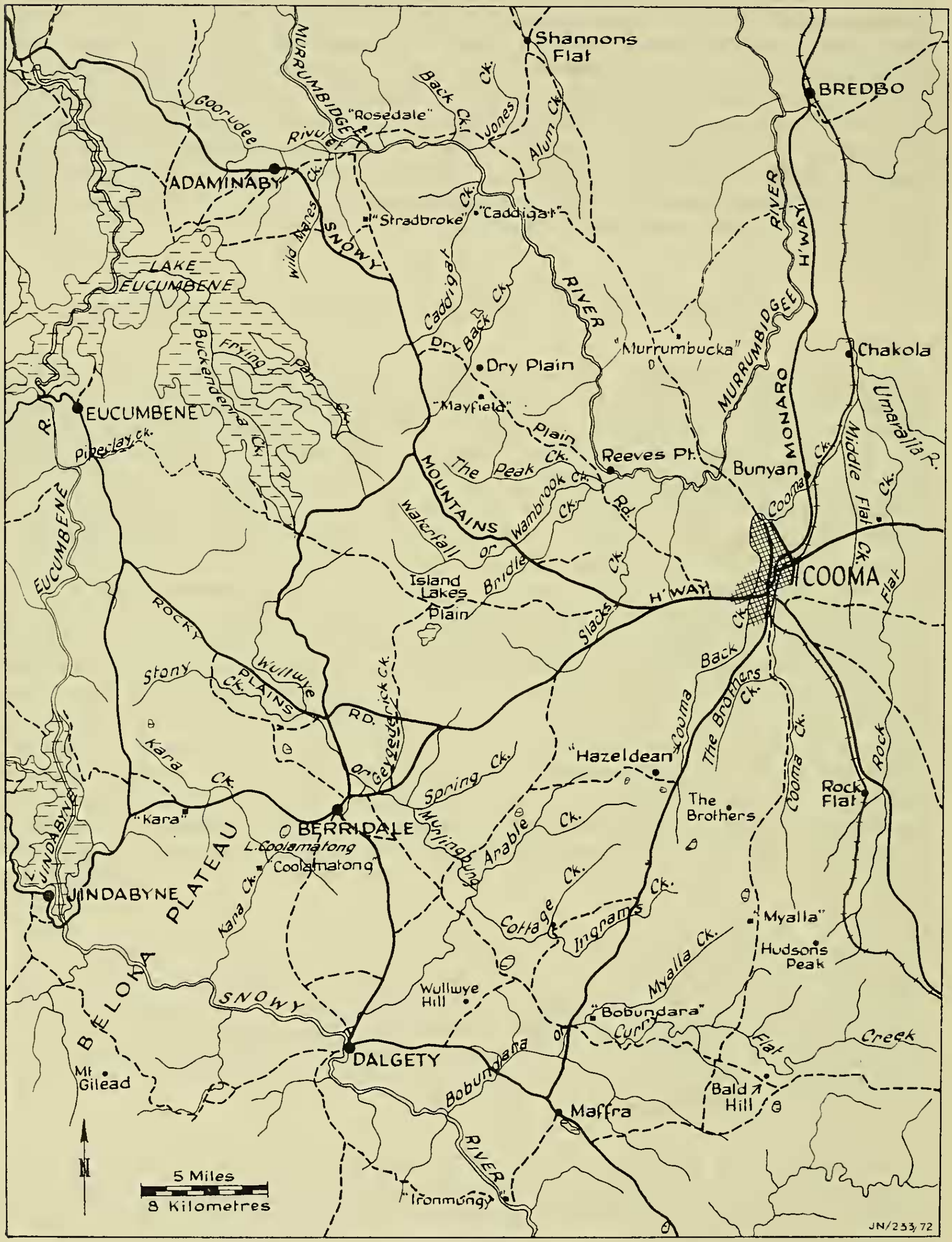
Shannons Flat
BREDBO
ADAMINABY
"Rosedale"
"Stradbroke"
"Caddigat"
LAKE EUCUMBENE
EUCUMBENE
Dry Plain
"Mayfield"
"Murrumbucka"
Chakola
Reeves Pt.
Bunyan
COOMA
Island Lakes Plain
"Hazeldean"
The Brothers
Rock Flat
BERRIDALE
"Kara"
L. Coolamatong
Coolamatong
JINDABYNE
PLATEAU
BELOKA
Wullwye Hill
"Bobundara"
"Myalla"
Hudsons Peak
DALGETY
Maffra
Bald Hill
Mt Gilead
"Ironmungy"
5 Miles
8 Kilometres
JN/233/72

Fig. 1.

The plateau is bounded on the SW by a creek which rises near the junction of the Jindabyne-Eucumbene and Rocky Plains roads and is a tributary of Stony Creek. On the left wall of its wide valley near its head is a long bank or ridge of gravels with an apparent thickness of 50 feet. Amid the gravels are rounded boulders of grey billy and vein-quartz up to 2 feet. On the top of the deposit near its NW end a patch of pebbly grey billy *in situ* some 20 feet by 9 feet was found, and traces of white clay were noticed on the road under the gravels. It seems that an earlier Tertiary deposit was superficially silicified under basalt and during the earlier-Pliocene exhumation was largely broken up and redistributed. It is probably significant that the gravel bank is collinear with a basalt-capped ridge 3½ miles to the SE separating Wullwye Creek from its tributary, Stony Creek. These two streams and their tributaries are locally bordered by gravel banks 30 or 40 feet above the present channels, and near their junction and debouchment on to the lowland north of Berridale a boulder-bed of brown quartzite appears at about 3,050 feet ASL, 150 feet above Stony Creek on its right bank, and terrace-gravels containing basalt and quartzite pebbles are seen at about 160 and 60 feet respectively above Wullwye Creek ; these may all be related to post-basalt differential uplift of the plateau.

Jindabyne Area.—A deposit, first noted by David on a field-trip in 1900, 7 miles from Berridale along the Jindabyne road where it is joined by the Hilltop track, nearly opposite Kara homestead, appears to be entirely sub-basaltic in character. A flat-topped hill, rising to about 100 feet above the floor of the upland valley traversed by the road, forms part of a ridge separating the east-flowing Kara Creek from a tributary, and is crowned with 30 feet of gravels. These, now much disturbed and reduced by quarrying, cover an area 470 yards by 380 yards, consist mainly of quartzite and chert, and are overlain by disrupted masses of grey billy up to 6 feet in diameter and 18 inches thick, obviously *in situ.* The base of the gravel is iron-cemented to a thickness of 18 inches. Basalt is absent.

At Jindabyne, a little north of the junction of the Kosciusko and Dalgety roads there was, before the filling of the Jindabyne reservoir, quite an extensive deposit of bedded white clay to be seen at 2,950 feet within the valley of Widows Creek. It was at least 20 feet thick, with an overburden of red soil, and may have been sub-basaltic. The nearest known basalt outcrops are six miles away, one on the Dalgety road resting on granite, the other at Jillamatong Hill, where a basalt cap overlies quartz grit and, I understand, white clay. These are all within the Jindabyne trough.

Some 8 miles south of Jindabyne the basalt-crowned monadnock of Mt. Gilead rises above the Beloka plateau to a little over 4,200 feet ASL. On the northern side Tertiary sediments under 130 feet of basalt have been changed to grey billy.

Berridale-Dalgety Area.—In the undulating country fronting the Beloka plateau and watered by south-flowing tributaries of the Snowy grey billy and its associates are prominent along Wullwye and Bobundara creeks and their affluents. The road from Cooma to Berridale at between 6 and 8 miles out traverses a number of very flat headwater branches of Spring Creek whose floors are strewn with small angular blocks of disintegrated grey billy, evidently related to remnants of basalt hard by ; where the Rocky Plains road takes off at 6 miles out of Berridale the rock is massive. From one of these valleys I have (1964) described grey billy surrounding a small lake, and more recently I have noted, some half mile south of the lake, an expanse of sandy grey billy, just above the floodplain, perhaps 200 yards square and broken into great slabs up to 15 feet in diameter and 5 feet thick, tilted at small angles in every direction. A little farther down bedded white clay of unknown thickness is exposed in shallow pits in the floodplain ; clearly its erosion has caused undermining and collapse of the grey billy. Not improbably the little lake was formed by a similar collapse.

Closer to Berridale near the junction of Geygederick Creek and Wullwye Creek at 2,820 feet ASL grey billy is seen amid projecting outcrops of quartz-diorite, and varying in texture from pebbly through sandy to a very fine-grained glassy type with smooth fracture; to this outcrop my attention was kindly directed by Dr. A. B. Costin, C.S.I.R.O., Canberra. Some $1\frac{1}{2}$ miles NNW of Berridale white bedded clay and leached bedrock slates are visible near basalt outcrops and overlain by post-basalt gravels, and near Wullwye Creek is a little basalt knoll amid alluvium and capped with gravels including a boulder of grey billy.

The Berridale-Bobundara road runs SE along the broad, flat valley of Wullwye Creek covered by remains of the basalt flows that once filled it, together with grey billy, sandy, gritty and pebbly, siliceous and ferruginous, in places cavernous through imperfect cementation. A very extensive outcrop is seen 4 miles out of Berridale, more than 600 yards wide and apparently up to 10 feet thick. It underlies 150 or 200 feet of basalt and rests on terraced basalt, which descends almost to creek level. Post-basalt gravels also border this stretch of Wullwye Creek at intervals, 20 feet above its present level. Three miles from Berridale on the same road granite bedrock is bleached and crumbles to a loose sandy clay under an old basalt-filled valley.

An interesting section is displayed along the track that takes off from the Bobundara road at 14 miles south from Cooma, traverses the plateau diagonally for 2 miles and then descends to the floor of Cottage Creek, dropping 500 feet in $2\frac{1}{2}$ miles. The plateau, 3,400 feet ASL, is composed of Tertiary basalt (30 feet) resting on Ordovician slates and quartzites. At the beginning of the descent, at about 3,300 feet, are what may be terrace gravels. At 3,100 feet a remnant of an old erosion-terrace or valley-floor with relics of grey billy on it is crossed. On the left of this a quarry-face in a sloping bank reveals dipping leached Ordovician slates and quartzites, with silicified gravels and boulder-screes of old quartzite. A little farther on a steep tributary creek crossing the track exposes cemented quartz-gravels on bedded white clay at 2,950 feet. Beyond this at 50 feet higher is an extensive flat or terrace on which a remnant of basalt 30 feet thick overlies ferruginous shale, cemented gravels and silicified rubble resting on a bedrock of leached slates. The track continues down to the creek, passing "Cottage Creek" homestead (2,820 feet), and crosses Ingram's Creek, which comes in from the east and joins Cottage Creek a little way downstream. Hereabouts may be seen silicified Ordovician quartzites and leached slates in the creek bed, and great disrupted blocks of pebbly grey billy traversed by quartz-veinlets on the bank of Ingram's Creek 40 feet above the creek and overlain by basalt. Cottage Creek makes a sharp bend to the right and after a meandering course of 5 miles or more joins Wullwye Creek at 2,620 feet. Just below the junction, and partly obscured by a landslide, basalt overlies grey billy, white clay (15 feet or more) and peat. The grey billy may be traced down Wullwye Creek for about half a mile, where it forms a terrace at 30 feet, with 20 feet of loose Pliocene (?) gravels on top. The drainage-area of Cottage Creek and its tributaries is about 2 miles wide and the evidence suggests the exhumation of an early-Tertiary valley, which had been gradually filled with basalt of a total thickness of at least 750 feet. During pauses in the extrusion sedimentation took place, and valley widening through encroachment on and erosion of the eastern wall of the valley.

The components of Bobundara Creek come mainly from the east, and there are indications that its valley and those of its tributaries were filled with basalt and interflow sediments through a vertical range of about 1,100 feet. Much of that at the higher levels was subsequently eroded away, but there are still relics of basalt along the sides and on the floors of the valleys, with outcrops of interflow and subflow sediments. Grey billy, bedded white clay, bole and leached slate bedrock have been noted in various places. Terraced basalt appears on the southern slope of Bald Hill up to at least 3,250 feet ASL, and 200 feet lower great blocks of grey billy, containing what appear to be fragments of vein-quartz, crop out. Bole and vitrified soil (?) underlie basalt at 2,900 feet on the road 1¼ miles SE of Maffra.

An unnamed tributary flowing south beside the Bobundara road 17 miles south of Cooma shows a good section in a road-cutting on its right bank. At 30 feet above the creek and 3,050 feet ASL is a prominent outcrop of pebbly grey billy with very little matrix, 4 or 5 feet thick, with thin interbedded lenses of fine, white siliceous material, probably silicified soil, containing casts of plant rootlets. The grey billy slabs rest apparently on loose gravel and are tilted ; the bedrock slates are leached and the silicified sediments are overlain by about 300 feet of basalt forming the surface of the plateau. The succession is exposed for 60 yards or more on the roadside and remnants of loose white quartz terrace-gravels continue down the creek for another 2 miles. Other outcrops of grey billy are seen near the mouth of Myalla Creek, which enters the main creek near " Bobundara ". Here Bobundara Creek, flowing on basalt at 2,600 feet, turns SW ; and 400 feet up on its right bank, a mile E of Wullwye Hill, is a large expanse of laminated white clay overlain by 6 or 8 feet of sandy grey billy. This has evidently been covered by basalt, of which patches still survive on the granite plateau surface.

Two miles to the south an instructive succession is revealed in road cuttings where the Dalgety-Maffra road descends through 400 feet in 2 miles to cross Bobundara Creek at 2,500 feet. No less than eight flows of basalt, ranging from 5 to 100 feet in thickness, alternate with beds of white clay (one of them 25 feet thick), lignite and grey billy. The first two have been superficially crumpled or corrugated by the push of advancing lava, and the lignite or peat seems to have experienced some heat alteration. At the top of the sequence is an apparent thickness of 150 feet of a massive breccia, chiefly of tight-packed boulders of argillaceous quartzite and slate, the latter as well as the matrix of the rock being leached. A 10-foot bed of white clay with lenses of very fine, white sand is interstratified with the breccia and is locally current-bedded. The whole mass has a downhill slope of about 10°, as if tilted by faulting. But for the presence of the clay the breccia might be taken for a kind of scree ; as it is, its interpretation is still to seek. A small remnant of basalt on top of it gives a clue to the leaching of the breccia and bedrock slate. At the surface, with the removal of the white-clay matrix the breccia weathers to a brownish ferruginous rubble. Much of the basalt is very decomposed and the granite basement that crops out near the river has been locally converted into loose, iron-stained sandy clay.

Two miles WSW of Berridale lies Lake Coolamatong, perched on a low, flat valley-divide 2,950 feet ASL. It is bordered by siliceous and ferruginous grey billy and has an overflow WSW into Kara Creek, which has descended steeply from the Beloka plateau to follow the base of its eastern scarp to the Snowy. Siliceous grey billy, gritty and pebbly, appears at 2,900 feet half a mile SW of the lake on the track to " Coolamatong " and half a mile farther on forms a terrace up to 2,880 feet, lying on leached slate bedrock at 60 feet above creek level. Farther down on the left bank short, steep tributaries flow over ferruginous and siliceous grey billy from nearly 3,100 feet ASL to 2,850 feet.

On the right bank behind " Coolamatong " homestead are terrace-accumulations of subangular pebbles and cobbles of slate, quartzite and grey billy up to 100 feet above the creek, and these continue north for about a mile along the scarp-foot ; they are not improbably Lower Pliocene, but near the base the rubble is silicified, and may be pre-basaltic. Silicified bedrock crops out here and across the creek at 600 yards south of the lake.

Along the Snowy at Dalgety (*cf.* Relph and Wynn, 1960) no sub-basaltic deposits have been noted, but at 100 feet above it on both sides are early Pliocene (?) high-level gravels. However, some 12 miles downstream on the right bank of the river at 100 feet up and 500 yards away from it, there is very coarse, gritty grey billy, with ill-defined pebble-bands, chiefly of milky quartz. The rock is disintegrating into rounded blocks up to 9 feet long, which bestrew the slope over a vertical interval of 50 or 60 feet, but the true thickness is probably not more than 10 feet. Though dimpled and cellular like that of normal grey billy, the surface is rough and the rock does not ring under the hammer.

On the opposite side of the river beside the road from Maffra to " Ironmungy " homestead is a knoll capped with grey billy about 3 feet thick resting on loose gravels, rounded boulders of it mingling with the gravels on the slopes ; the total thickness may be about 50 feet. As the knoll is about 100 feet above the river and 400 yards away, it would appear that the earlier-Tertiary ancestor of the Snowy was much bigger than the present stream. A few miles south grey billy crops out under basalt along Lambing Creek, a Snowy tributary.

Murrumbidgee Basin (Fig. 1)

Adaminaby Area.—The eastern half of the Adaminaby plateau as well as the country north of it is drained by the Upper Murrumbidgee and its tributaries. From the north come Jones Creek and Alum Creek. Where the former is crossed by the Rosedale-Murrumbucka road there is a considerable expanse of grey billy *in situ*, most of it pebbly, its top at 3,260 feet ASL, or 60 feet above the creek ; it continues down creek for at least 600 yards. Alum Creek is crossed by the road 3 miles farther on but has been rejuvenated here to a level well below its pre-basalt one ; there are, however, high-level gravels (? Pliocene) at 80 feet above it. Some miles upstream, where the Cooma-Shannons Flat road follows it closely, Alum Creek occupies a wide, flat swampy valley in which pebbly grey billy crops out a little above creek-level at intervals beside the road from 3 miles S of Shannons Flat school to three quarters of a mile beyond it. There is at least one small patch of basalt on ferruginous grey billy at 3,600 feet.

The country around Adaminaby is traversed by tributaries of the Murrumbidgee. A little north of the township Goorudee Rivulet flows east to join the river a quarter of a mile below Rosedale bridge. Where the Yaouk road from Adaminaby crosses it at about 3,280 feet ASL sandy grey billy, cavernous and disintegrating into large blocks, crops out 20 feet above the swampy valley floor. Other outcrops at a higher level have not been examined.

A mile east of Adaminaby a road takes off to the SW from the Snowy Mountains Highway. Half a mile along it a little craggy outcrop of cemented gravel overlies bedded white clay 20 feet thick resting on leached slate bedrock at 3,390 feet, 25 feet above the swampy valley of Happy Valley Creek. At $1\frac{1}{4}$ miles further on, at 3,550–3,600 feet, the road crosses an exposure of siliceous and ferruginous grey billy at least 100 yards wide. This obviously pre-basalt deposit is roughly 150 feet above those beside Happy Valley Creek.

Some $3\frac{1}{2}$ miles east of Adaminaby on the road leading to Rosedale bridge (where the Murrumbidgee flows at 3,190 feet) and $1\frac{1}{2}$ miles SW of the bridge a prominent vertical outcrop of silicified Ordovician quartzite is exposed at 3,210 feet as a faulted mass flanked on either side by leached slates. The outcrop continues southwards as the crest of a steeply-sloping ridge and is traceable for $1\frac{1}{2}$ miles to an altitude of 3,470 feet ASL. The silicified rock is typically white, closely resembling that from Rock Flat described above. It is thought that silicification and bleaching were related to a former basalt-flow that occupied the Murrumbidgee valley almost down to its present floor level ; such a suggestion is in harmony with the evidence of grey billy and white clay deposits but little above the valley floors of Goorudee Rivulet, Happy Valley Creek, Jones Creek and other tributaries in their lower reaches.

The country traversed by the Snowy Mountains Highway for 5 miles south from Adaminaby abounds in exposures of grey billy and its associates, of which sections are visible on and near the road itself and along side-tracks. The highest exposure occurs at 3,600 feet ASL some 500 yards south of the track to " Stradbroke " ; here grey billy with angular chips of black silicified slate is underlain by white clay and has a distinct slope down from the road. Extensive outcrops may be seen along the " Stradbroke " track east and the old Adaminaby track west of the Highway, where the base of the grey billy, resting on white clay, descends to 3,450 feet. The total east-west width disclosed exceeds 2 miles but diminishes considerably northwards. Nearer Adaminaby where the highway crosses Wild Mares Creek at 3,330 feet an extensive remnant of pebbly grey billy 40 feet up the right bank of the creek has been broken, apparently through undermining, into great slabs, one of them 18 feet by 18 feet, another 20 feet by 9 feet, and none more than 4 feet thick. Most are tilted, and the underlying white clay is traceable for a quarter of a mile down the creek, whilst leached bedrock is exposed beside the highway for more than 150 yards west of the creek.

Bedded white clay may also be seen at intervals along the highway in road cuttings and eroded valley flats. It is particularly well displayed in two cuttings each 10 or 12 feet high, one 400 yards north of the " Stradbroke " turn-off at 3,540 feet, the other three-quarters of a mile farther north at 3,450 feet. In the latter the well-laminated sandy clay containing obscure plant remains is truncated at its northern end by a contemporaneous washout wherein white clay is interlaminated with narrow bands of quartz-granules and mica-flakes. Some 300 yards south, in a flat tributary valley west of the highway, at about 20 feet lower than the cutting, tilted cavernous grey billy rests upon white clay.

Leached slate bedrock is seen in some places, as noted above. Of particular interest is an exposure on the highway between the more northerly white-clay cutting and the Wild Mares Creek bridge. This is visible for about a quarter of a mile at an altitude ranging from 3,400 to 3,450 feet ; the low watershed of Wild Mares Creek and Stradbroke Creek is traversed by the highway for 1½ miles, and this is the only stretch of it that is not composed entirely of Kainozoic deposits.

Even if allowance is made for the effect of the northerly slope of the valley floors, it is hard to explain the varying altitude of grey billy along the highway, particularly as compared with that of the white clay in adjacent outcrops. It may be due in part to the breaking up, tilting and lowering of the hard crust through undermining, by removal of subjacent clay as the result of erosion, a suggestion originally made to me by Mr. Moye ; another possible explanation is faulting, of which, however, no traces have been seen.

On the road that runs south from Rosedale bridge to join the Snowy Mountains Highway grey billy and leached slate are seen up to an altitude of 3,450 feet and grey billy appears also in the valley of a creek just east of the road.

Internal evidence makes it clear that though the nearest basalt outcrop is 2½ miles away to the east, the altered sediments described above and the valleys in which they lie antedate the lava outpourings and were once themselves covered with basalt.

Post-basaltic deposits are not uncommon, locally obscuring the earlier-Tertiary beds. They overlie the cemented gravels on the Happy Valley road and on the road from Adaminaby to the Rosedale bridge at 3,350 feet, where they are seen to consist of boulders and gravels including waterworn grey billy. They appear to form much of the surface in Adaminaby and its immediate vicinity and in the country drained by Wild Mares Creek and Stradbroke Creek. Here they partially cover the grey billy and white clay, forming flat-topped, somewhat dissected banks, up to at least 50 feet thick, of subangular boulders and pebbles of brown quartzite, hard black slate and grey billy in a matrix of transported red clay. In the two road-cuttings in white clay mentioned above they lie unconformably on the clay, and near the base include layers containing, *inter alia*, slabs of iron-cemented grey billy. These deposits, lying on the floors of mature upland valleys, are thought to be probably earlier-Pliocene.

Certain boulder-beds (Adamson, 1955) along the left bank of Wild Mares valley look like scree-deposits. They are composed of angular and subangular boulders up to 4 feet long, mainly of quartzite and iron-hardened slate, derived from the somewhat steep walls of the valley and embedded in soil. Obviously post-basaltic, they may be of Pliocene or even Quaternary age.

A few miles to the SE deposits of an ancestral Caddigat Creek may be studied on the Dry Plain road, a mile east of its intersection with the Snowy Mountains Highway, on top of a low, flat ridge at 3,800 feet ASL. This forms the watershed between Caddigat Creek and Back Creek, both here occupying old-mature upland valleys at about 100 feet lower. Cemented gravels and interbedded white clays to a total thickness of perhaps 20 feet lie upon leached bedrock slates. Locally the gravels are iron-cemented, but elsewhere their clayey matrix is bleached, and along the track running NNE from the Dry Plain road occasional fragments of grey billy may be seen amid black basaltic soil. A few miles north, where the Tertiary deposits cross to the west of Caddigat Creek, sections of them are revealed through deepening of the creek, and they spread out for about a mile on a low, gently-sloping plain at 3,600 feet. Near " Caddigat " homestead they descend to 3,450 feet ASL, but beyond it the creek and its tributaries are deeply entrenched, and I have not examined them. In addition to siliceous grey billy there are, especially in the northern part of the area, iron-cemented grits and coarse sands etched out by weathering into a maze of anastomosing tiny ridges, apparently because of rhythmical cementation. Some of the siliceous grey billy is made up largely of rounded pebbles and occasional large blocks of vein-quartz in a matrix of coarse gritty quartz-grains. Basalt, fairly extensive in the south, is reduced in the north to scattered patches, many in visible or virtual contact with the sediments.

A few post-basalt accumulations have been noted. On the Snowy Mountains Highway 350 yards north of the Dry Plain road junction is a section of 15 feet of cobbles of old rocks, rounded and subangular, with a few lenses of sand, on the floor of a Caddigat tributary. The land-surface west of " Caddigat " homestead is strewn with large blocks of Ordovician quartzite, vein-quartz and grey billy, due to flood distribution possibly in Recent time, and a creek bed nearby is choked with boulders of siliceous grey billy. These deposits extend for more than a mile west of the homestead.

The highest altered sub-basaltic deposit I have observed is at " Mayfield ", three-quarters of a mile west of the " Glenbernie " turn-off on the Dry Plain road, 4 miles south of its junction with the Snowy Mountains Highway. It is an interflow deposit of bedded white clay, possibly 10 feet thick, with its top at 3,980 feet ASL, and is overlain by perhaps 100 feet of basalt. At " Elanora ", half a mile to the north, it emerges from under the basalt and apparently forms part of the section visible along the Dry Plain road just north of the " Glenbernie " turn-off ; this may be 40 or 50 feet thick, and includes, under the clay, a thin bed of gravel and a 2-foot layer of peat resting on or against leached bedrock. The whole succession seems to be a remnant of sediments deposited on the valley floor of an ancestral Back Creek. Indeed, 1½ miles to the NE basalt on the ridge at 4,000 feet extends down to the floor of Back Creek valley at 3,600 feet and continues west on to the top of the flat ridge that bears the sub-basaltic

Caddigat gravels. The evidence suggests at least two episodes of lava extrusion separated by crustal uplift and erosion.

Dry Plain road continues SE down along the sloping comb of a ridge to near the Murrumbidgee at Reeves Point, descending 1,400 feet in 6 miles. Many years ago Mr. F. A. Craft kindly told me of sub-basaltic deposits visible on the road. The upper, at between 3,500 and 3,600 feet ASL, consists of ferruginous gravel overlain by possibly 50 feet of bedded white clay ; the other at about 3,280 feet is a much less conspicuous bed, perhaps 10 feet thick, of loose well-rounded pebbles of quartzite and vein-quartz. Both deposits lie on leached slate bedrock and are overlain by basalt. The full significance is not at the moment apparent.

On its way to Cooma the road crosses The Peak Creek, a Murrumbidgee tributary, on basalt at 2,600 feet, and on both sides of the river where it turns east basalt appears at but little above its present level. Also within its valley there are post-basalt gravels at 100 feet above the river ; these may be contemporaneous with some of those shown on Adamson's map as bordering the Murrumbidgee further north.

The Country around Cooma.—Two meridional belts of basalt, each up to more than a mile wide, pass about 8 and 10 miles respectively to the west of Cooma, but little alteration seems to have accompanied their extrusion. The only notable example is to be seen at 3,300 feet ASL one-quarter to one-half mile west of the Snowy Mountains Highway where it crosses the summit of a ridge separating Slacks Creek from Bridle Creek. The succession has been much confused by quarrying operations, but a small outcrop of pebbly grey billy about 10 feet thick is visible in one place, and elsewhere a few feet of ferruginous grit and gravel, both apparently resting on loose gravels of unknown thickness. A little white clay shows at one point and bedrock of quartzite and slate traversed by quartz-veins seems to have been locally silicified. The creeks are 400 and 300 feet respectively below the summit of the ridge, and patches of basalt that once filled their broad valleys are to be seen almost to the top of the ridge. The outcrop of grey billy is 30 or 40 feet higher than the nearest basalt outcrop, but it is difficult to determine which is the younger. Certain it is, however, that a pre-basalt river once flowed at a considerable height above the present creeks ; it may have been the common ancestor of both.

The deposits on the Island Lake Plain road depicted as Tertiary on Hall's (1955) map are scree-like or rubbly accumulations chiefly of brown Ordovician quartzite, angular to subangular, mantling outcrops of weathered Tertiary basalt. They may have been partly stratified by water-action and are Pliocene or younger.

Leached slate bedrock under basalt is seen on the Snowy Mountains Highway where it descends the right bank of Bridle Creek valley on the Adaminaby road about 8 miles out from Cooma, and on the Cooma-Dry Plain road where it leaves the plateau at 3,000 feet and drops down steeply into a youthful tributary of Bridle Creek.

Much of the country south and east of Cooma is basalt-covered and many tributaries of the Murrumbidgee clearly had a pre-basalt existence. For instance, the bed of Cooma Back Creek, where it is crossed by the Bobundara road 9 miles south of Cooma, is 10 feet below basalt-covered grey billy, and 5 miles to the north at " Woodstock " gate and for 500 yards south of it there are uncemented white gravels underlain by white clay at 2,850 feet, which a little distance south disappear under basalt. A mile to the east and at 150 feet lower disintegrating sandy and gravelly grey billy with white clay crops out in the valley of The Brothers Creek, a tributary of Cooma Creek, as sub-basaltic and interflow deposits, and continue across the Myalla road on to the floor of Cooma Creek valley. Occasional outcrops of grey billy appear further up the valley, and interflow beds of white clay further south along the Myalla road. In the basalt country south of Cooma grey billy has been noted on the west-east track from " Hazeldean " homestead to the Bobundara road and interflow white clay on the Nimmitabel road near Rock Flat.

Post-basalt gravels and cobbles of redistributed grey billy have been observed in Cooma beside the railway half a mile south of the railway station at about 20 feet above Cooma Creek.

The country north and north-east of Cooma is undulating, consisting of low submeridional ridges of old rocks, rising to upwards of 2,700 feet ASL, separating wide, shallow valleys and in places crowned with remnants of Tertiary basalt which extend down into the valleys ; the latter also contain pre-basaltic and post-basaltic sediments. These features are well seen on either side of the road from Cooma to Numeralla for its first 10 miles. From the western bounding ridge of Middle Flat valley basalt extends down the side of the valley, and at a mile north of the road a deposit of diatomaceous earth is partially surrounded by basalt and locally hardened and converted into common opal. Farther north Silurian dacitic crystal tuff is changed to white clay studded with tiny quartz grains. Cobbles and boulders of redistributed pebbly grey billy appear on an old flood-plain 40 feet above the creek channel, which is cut in leached quartzites and slates. The next ridge, separating Middle Flat from Rock Flat (Tolbar) Creek valley, is capped by a small outlier of basalt at least 100 feet thick a quarter of a mile north of the road. Some 50 feet below it is a layer of siliceous grey billy *in situ* but breaking up into rounded slabs 10 or 12 feet in diameter by 2 feet thick, poorly cemented, cavernous, and strewing the ground with weathered-out pebbles. Polygonal surface-cracking of the slabs is common, and they are tilted in all directions. Between basalt and grey billy the section is obscured by a veneer of post-basalt (earlier-Pliocene ?) gravels, cobbles and boulders of vein-quartz, black slate, brown quartzite and basalt, which covers the slope for some distance north and south. On the road these gravels, which extend for nearly a mile east to Tolbar Creek and through a vertical range of 50 or 60 feet, lie on white clay possibly 15 feet thick with the bedding emphasized by thin laminae of limonite. This may be stratigraphically below the grey billy described above ; it appears to underlie basalt and to rest partly on a thin basalt flow and partly upon bedrock. It contains obscure plant remains and is gently flexed with a low easterly dip. Locally, bedrock slate has been leached and limestone and crystal tuff replaced by limonite. Across Tolbar Creek (2,485 feet) the road keeps on its easterly course on a high-level flood-plain about 100 feet above a tributary creek for a mile, and then rises toward the eastern wall of the valley. At 2,750 feet a cutting reveals 8 feet of waterworn cobbles sitting unconformably upon about 20 feet of white clay passing down into ferruginous sands, which rest on leached bedrock slates and quartzites. The clay with its thin limonitic laminae closely resembles that on the western side of Tolbar Creek but is 200 feet higher. It is considered to be pre-basaltic and the overlying cobbles, consisting of white quartz, brown quartzite and grey billy (?), are thought to be post-basaltic. Another 2 miles and the road reaches its highest elevation of more than 3,000 feet, where it traverses the face of a north-sloping ridge, the watershed between the Umaralla River and its tributary Tolbar Creek. Here it skirts the base of a Tertiary basaltic outlier that rises southward more than 200 feet to the flat summit of the ridge. There appear to be three flows of basalt, the topmost being 110 feet and each of the others less than 30 feet thick. On the top of the ridge, immediately south of the basalt outcrop and at a slightly higher level are scattered fragments of grey billy and ferruginous shale, possibly relics of deposits under a flow now vanished. Beneath the topmost flow are 70 to 80 feet of coarse quartz-grits, fine gravel, plant-bearing shales and, at the base, quartzitic boulder-beds. The middle flow seems to be underlain by white clays with corrugated or rucked-up surface, ferruginous shales and iron-cemented gravels, whilst the lowest flow rests on semi-consolidated gravels. In several places where contact with the Tertiary rocks is exposed the bedrock of Ordovician phyllites is leached. The lowest basalt has been traced in a direction N 18° E (true) for 480 yards along a flat spur on the Umaralla side of the watershed. There are also signs of basalt and sub-basaltic deposits on the western side of the ridge 400 feet above Tolbar Creek.

The basalt so abundant south of Cooma dwindles and disappears to the north. Some 3 miles out along the Monaro highway a few large boulders of grey billy may be seen in the basalt country, and at $1\frac{1}{2}$ miles north of Governors Hill and 130 feet above the Umaralla River is a solid outcrop of pebbly grey billy at 2,460 feet ASL. East of Governors Hill within the wide valley of Cooma Creek grey billy has been noted at about 2,450 feet, and basalt overlying grey billy has been observed 2 miles to the north and at approximately the same level within the valley of a small creek flowing north to the Umaralla River ; it is mantled by high-level gravels, which also rise in places above the flood-plain of the river and its tributaries to 2,470 feet or more. Beside the railway line at three-quarters of a mile south of Chakola Siding at the very edge of the Umaralla River is a small patch of basalt at about 2,400 feet. These are the most northerly outcrops of basaltic lava and sub-basaltic sediments known to me in this stretch of country.

Country North of Cooma.—Downstream of its confluence with the Umaralla River the Murrumbidgee is bordered by many remnants of terrace-gravels at altitudes up to 240 feet above the present river (Browne, 1944), extending at least as far north as Michelago ; the presence of occasional cobbles of basalt and grey billy among them indicates a post-basalt age. However, on the highway some 3 miles south of Bredbo a couple of cuttings reveal sections through white, bedded clays not less than 25 feet thick, truncated by beds of river gravel at least 30 feet thick ; these are in a shallow valley at about 2,400 feet, or 100 feet above the river, which is about half a mile to the west with a gravel-crowned ridge at 2,540 feet in between. The gravels, lying unconformably on the clay, consist of black, hardened chiastolite slate, quartzite, silicified rhyolite, grey billy in large boulders and acid gneissic granite such as is got *in situ* on the left bank of the river. Its presence suggests that the gravels mark the bed of an early Pliocene (?) ancestor of the river which had also been occupied by its earlier-Tertiary progenitor.

If the patch of silicified breccia on felsite $1\frac{1}{4}$ miles to the north and at about the same altitude is accepted as of sub-basaltic origin, and account is taken of the basalt dykes which have been noted at intervals from Bredbo to a few miles north of Michelago, we may with some justification assume that earlier-Tertiary basalt formerly extended for some 45 miles north of Cooma in the Cooma-Canberra corridor. Details of the geology of the 25 miles of country thence to Canberra I have not studied.

Summary of Inferences

From the information presented above regarding the areas examined the following generalizations emerge :

(1) The earlier Tertiary drainage-pattern was in many places very similar to that of the present day.

(2) The earlier Tertiary topography was gradually buried under basalt over a considerable time-interval to a depth of at least 1,200 feet above some of the valley-floors.

(3) Later, possibly in early Pliocene time, prolonged erosion removed much of the basalt and to a large extent restored the landscape to its pre-basalt condition but left some evidences of its previous presence, particularly in the river-valleys.

(4) Later again, but still in the Pliocene, erosion was succeeded by deposition in the exhumed valleys and the deposits were in their turn somewhat dissected.

(5) The arterial rivers—Eucumbene, Snowy, Murrumbidgee and Umaralla—participated in these happenings, but subsequent erosion has removed the evidences more thoroughly than in their tributaries.

Canberra-Lake George Area

Evidences of Tertiary volcanic activity in Canberra and the adjacent country are very scanty. Öpik and Noakes (1954) both make mention of the " Fyshwick Gravels ", which the former (1953) regarded as Permian (?) fluvio-glacial deposits, but which as later examination has shown are clearly remnants of grey billy. They were exposed in a small, shallow quarry in the industrial suburb of Fyshwick, but, unfortunately, all traces of them are now buried beneath buildings and industrial rubbish. They occurred on a low ridge sloping north to the Molonglo River and about 50 feet above it. As revealed in the quarry, a large rounded and dimpled block of typical grey billy was surrounded by and partially embedded in stratified quartz-gravel, and 150 yards to the north-west were the remains of a sheet of grey billy *in situ* in process of disruption, the biggest slab being 9 feet by 2 feet by 1½ feet ; there were some loose gravels around them, and the fact that the grey billy was devoid of pebbles suggests that the gravels may be of later age, possibly early Pliocene. Other outcrops of unconsolidated gravel scattered about the city (e.g. near St. John's Church on the north side of the valley) have been thought to belong to the same group (Legge, 1937).

Taylor (1907*b*) recorded that shafts sunk through the gravels and boulder-beds on the western wall of the Lake George depression disclosed the presence of underlying white clays ; he also noted white clays on the floor of the lake, and a quartzitic rock later identified by Garretty (1937) as grey billy. Some 5 miles south of Bungendore between the road and the Captains Flat railway line is a great expanse of leached Ordovician slate, of whose existence I learnt through the courtesy of Dr. and Mrs. F. H. Morley of Canberra. It forms part of the floor of the wide valley-plain in which farther south the Molonglo River flows. The leached slate extends over, perhaps, 100 acres or more and is said to be 30 or 40 feet thick.

Farther south the western wall of the wide Molonglo valley is bordered for several miles by remnants of a terrace above the flood-plain. At a spot on the Queanbeyan-Captains Flat road about 13 miles south from Bungendore one of these is capped by quartz-gravel, sand and clay, all iron-impregnated, and resembling some of the altered sub-basaltic deposits of the Monaro country described above. The nearest known Tertiary basalt (Garretty, 1937) is a small patch 10 miles east of Lake George and 2 miles south of Tarago.

It is tempting to speculate that basalt once filled the lowland corridor running north from Cooma to Canberra and Queanbeyan and that it spread down along the Molonglo valley to Lake George and the country east of it.

Shoalhaven Basin

In his admirable series of studies of the physiography of the Shoalhaven River valley Craft (1931*a*, 1931*b*, 1931*c*, 1932*a*, 1932*b*) lays considerable stress on the role of Tertiary basalts and their associated " contact quartzites ". An important physiographic feature recognized by him is the Shoalhaven Plain, an extensive undulating surface sloping gently north at between 2,400 and 2,000 feet ASL, bounded east and west by higher land and forming the flat-floored very mature valleys wherein the river and its tributaries flow. It is traceable from the headwaters to below the great right-angled bend at Tallong. Basalt remnants crop out upon it here and there, some of considerable size, as at Nerriga and downstream from Tallong to Caoura. As well as white clays and sands with some peat, abundant outcrops of grey billy and ferruginous conglomerate are scattered over the surface, many of them bordering the river and its tributaries. Some are in close relation to basalt (Craft, 1931*a*, pp. 111, 118–119 and Pl. VI) and are evidently *in situ*; these may pass down into uncemented sands or gravels or may rest directly on leached bedrock. Others are incorporated as subangular blocks and rounded pebbles and boulders in later rudaceous accumulations; they have evidently been broken up and the fragments redistributed by river-action following the almost complete removal of the basalt. On the road from Braidwood to Nowra, part of which traverses the Shoalhaven Plain obliquely, three outcrops of grey billy and a few small patches of basalt and of unsilicified gravels are crossed in a distance of 20 miles.

In the upper parts of the basin the Shoalhaven Plain has had channels incised in it to a depth of 300 or 400 feet; farther down there has been later rejuvenation with the excavation of deep gorges, so that at Tallong, 40 miles from the coast, the Shoalhaven Plain is 1,600 feet above the present stream.

The history of the evolution of the present river system seems to have in general paralleled that of the Snowy and Murrumbidgee, but can be carried a little farther. An ancestral Shoalhaven with tributaries existed in earlier-Tertiary time and was later filled with basalt, which caused alteration of the pre-basalt sediments. Following the Miocene peneplanation the Macleay uplift resulted in re-excavation of the valleys to a little below the pre-basalt level and in their expansion to form the Shoalhaven Plain. Most of the basalt vanished and much of the sub-basaltic material was broken up and redistributed. Later there was moderate regional uplift and entrenchment of the main streams for a few hundred feet, and lastly, in closing Pliocene time, the Kosciusko uplifts initiated the vigorous erosion and rejuvenation that is still proceeding.

The sequence of events is well illustrated within a relatively small area around Tallong where the river turns east and makes for the coast.

South Coast

The outcrops of grey billy described from the neighbourhood of Milton and Moruya (Brown, 1926) are up to 80 feet above sea-level and 15 feet thick, and in a few places are in visible contact with overlying basalt. Both sandy and pebbly types are present and in one deposit common opal was recognized. Joint-blocks of the rock were found to have crumbly white sandstone or loose sand at the core, as if silicification had been incomplete. Some of the basalt is unaccompanied by grey billy and in a few places it rests on white clay.

Farther south both basalt and Tertiary gravels are locally prominent. Some gravels and sands are younger than the basalt, as at Broulee Island north of Moruya, some are not in visible relation to basalt and others are clearly sub-basaltic, but only at Brow Lake north of Narooma are they known to be silicified. Leached bedrock near Coila Lake may be related to basalt close by.

Macquarie Basin

The Macquarie River flows north and west from the Main Divide of eastern Australia to join the Darling; it has two chief headwater components, Campbells River and Fish River. The country drained by these was evidently once covered with Tertiary basalt, which now appears as isolated masses great and small, mostly valley-fillings that very probably belonged to more than one phase of earlier Tertiary volcanicity. Some remnants straddle the Main Divide at more than 4,000 feet and in many places the flows are underlain by sediments. Five miles ENE of Oberon Nunans Hill, rising to an altitude of 3,750 feet ASL, adjacent to a tributary of Fish River, is capped by 125 feet of basalt resting on iron-cemented quartz-gravel, and around Oberon at more than 3,600 feet basalt fills broad, mature valleys overlying river-deposits of quartz-gravel and boulders with a thickness of as much as 40 feet ; locally, these deposits have been silicified and/or iron-cemented. Fifteen miles west of Oberon at 3,250 feet ASL, the road to Rockley crosses the flat-topped ridge forming the watershed between Campbells River and its tributary Sewells Creek. It is capped by 150 feet of basalt in two flows separated and underlain by sediments which are in places silicified. Sewells Creek is nearly 500 and Campbells River 700 feet below the top of the ridge, and it seems that the two streams are descendants of an ancestral river that in pre-basalt time flowed where the watershed is today, a condition that has also been described for other rivers in this State (Browne and Raggatt, 1935). South-west of Rockley pebbly grey billy has been noted at 2,850 feet ASL, some 70 feet above Peppers Creek, and a few miles north of the township, where the road to Bathurst traverses the broad valley of Fostars Creek, grey billy and iron-cemented alluvium crop out where the present valley-floor coincides approximately with the pre-basalt one.

Upstream of Bathurst Campbells River and Fish River unite to form the Macquarie, which traverses a widely expanded undulating lowland cut in granite and forming the Bathurst Plains. Relics of pre-basaltic valleys in the shape of basalt outcrops and altered sediments rise above the general level forming an arc roughly concentric with a wide curve in the present river (Curran, 1891 ; Ross, 1898). Along the road from Rockley the first evidence of former valley-filling basalt is seen on a hill half a mile south of Georges Plains and 8 miles south of Bathurst. This rises to about 2,400 feet ASL and 130 feet above the wide, alluviated and terraced valley of Vale Creek, a tributary of the Macquarie. The hill is crowned with siliceous conglomeratic grey billy in process of disintegration and the fluvial deposit may be 50 feet thick.

The most considerable mass of basalt forms the level-topped capping of Mt. Panorama ridge on the southern outskirts of Bathurst, more than half a mile long and rising to 2,878 feet ASL, or about 750 feet above the river. It is apparently 100 to 150 feet thick and rests upon alluvial deposits that include quartz-gravels, sand and clay and granite rubble. Locally the sands and gravels have been converted into grey billy, some of which, incorporating numerous fragments of white quartz, may easily be mistaken for broken-up vein-quartz. A few feet of white sand and sandy clay were reported from immediately under the basalt on the eastern side of the ridge. The thickness of the deposits where measured is about 20 feet, but may exceed this elsewhere.

Small outliers of basalt appear, mostly to the north-west of the Mt. Panorama mass, the most conspicuous being that at Mt. Pleasant, underlain by 40 feet of uncemented quartz-gravel. The top of the deposits at Georges Plains and Mt. Pleasant is at 2,400 and 2,360 feet respectively, whereas on Mt. Panorama it is at about 2,720 to 2,770 feet ; the difference in altitude may be explained by supposing that the higher beds were laid down in an earlier channel of the ancestral river.

At lower levels in the surrounding country are accumulations of alluvial gravels evidently much younger than those just described and probably, in part at least, of Lower Pliocene age (Curran, 1891).

Downstream from Bathurst the Macquarie valley and that of its tributary Bell River contain remnants of basalt (Harper, 1909 ; Colditz, 1942). Some of the flows rest on alluvial deposits but, so far as I know, no grey billy has been reported. At Dubbo the valley is very wide and alluviated and the country is gently undulating. Tertiary basalt appears on both sides of the river (Curran, 1885), lying directly on Jurassic strata or on Tertiary alluvium. A quarry but little above present river-level revealed a deposit 15 or 20 feet thick of small, white gravel with bands of ferruginous material, whose top surface is locally capped with amygdaloidal basalt. Elsewhere layers of Jurassic sandstone and shale overlain by patches of basalt are iron-impregnated at the surface but bleached white lower down, and Curran recorded basalt lying on a few feet of white clay.

On the Peak Hill road some 2½ miles out of Dubbo is a ridge of iron-impregnated gravels with odd boulders up to 2 feet in diameter ; the age of these deposits is not known, but their alteration is conceivably related to the former presence of Tertiary basalt.

Other Localities in the Central Highlands

Elsewhere in the Central Highlands belt evidences of alteration of alluvial deposits by Tertiary basalt have been noted as, for example, in the Trunkey (Arthur) area some 30 miles SSW of Bathurst, where Raggatt (Browne and Raggatt, 1935) found sub-basaltic " drift " locally converted into siliceous grey billy and forming terrace deposits at 50 feet above present creek-level.

The Tertiary basalts of the Mittagong Range between Mittagong and Robertson are in places underlain by ferruginous gravels (Taylor and Mawson, 1904). An extensive deposit of white clay, fine quartz-gravel, ferruginous gravel and grey billy revealed by a quarry on the Moss Vale-Nowra railway near Burrawang, 8 miles east of Moss Vale, is clearly related to adjacent olivine-basalt, whilst on the Hume Highway 4 miles north of Berrima and 3 miles west of Bowral a fine example of leached Triassic shale in direct contact with Tertiary basalt is seen in a new cutting. The basalt is much deuterized.

In the Orange district at Spring Hill, Millthorpe and elsewhere white clays under basalt have been noted. In the vicinity of the village of Neville, 15 miles south of Blayney, I found grey billy by the roadside, and on the Cudgegong road some 12 miles from Mudgee an accumulation of grey billy boulders up to 18 inches in diameter at 40 or 50 feet above the level of the present Cudgegong River. In each of the last two instances the grey billy has evidently been redistributed by river action, though not borne very far ; its presence suggests the exhumation of an earlier Tertiary valley and a former filling of basalt where now there is none.

Palaeozoic bedrock slates converted into white clay immediately under Tertiary basalt have been observed at Kings Plains, 7 miles east of Blayney, and at a point a few miles west of Taralga near Crookwell, and it seems likely that some of the white kaolinic clays in the Mudgee district and elsewhere (Morrison and Raggatt, 1928, p. 217) are altered sub-basaltic bedrock.

Lower Hunter Valley

Raggatt (1939) examined occurrences of grey billy along the Lower Hunter River and ascribed their formation to the influence of Tertiary basalt now vanished. I have been able to supplement and extend his observations and to show that the deposits are quite widely distributed along the river. A number of them were noted by David (1907) and are marked as High-Level Gravels on the geological map accompanying his Memoir. Actually, as is indeed implicit in Raggatt's description, they belong to two separate epochs of deposition.

In addition to those noted by Raggatt on the Denman-Muswellbrook road and at Jerrys Plains and Abbey Green near Singleton, remnants, some of them considerable, have been examined at 200–250 feet ASL on the left bank of the river between Singleton and Glendon, on the right bank 1½ and 2 miles SSW of Glendon, and at Lower Belford. Farther downstream they have been noted at Dalwood north of the Luskintyre bridge near Lochinvar, and at Gosforth (Browne, 1927). The most easterly occurrence examined is on the right bank 3 miles due north of West Maitland near the site of the former Melville bridge. A detailed search would, doubtless, reveal other occurrences.

The original grey billy is mostly in large blocks 3 feet and more in length, often stoutly tabular with rounded edges ; one block at Gosforth measured 6½ feet by 4 feet by 3 feet. This material is obviously *in situ* or virtually so ; at Abbey Green it is seen in process of disruption along joint-planes. Some of it is silicified sand, some silicified gravel with well-rounded pebbles up to 2 or 3 inches and small chips of chert. The deposits are usually in the form of low hills or ridges between 100 and 130 feet above the river.

In close association with the grey billy *in situ* there is an abundance of loose, well-rounded material ranging in size from large boulders to fine gravel. In certain places, as at Abbey Green, South Belford and Belford church, this is dominantly of grey billy but it usually includes recognizable Carboniferous lavas—rhyolite and toscanite, some apparently silicified—with silicified wood (Permian ?), black chert and red jasper. At Jerrys Plains there are pebbles of hard, ferruginous shale and sandstone ; in the Denman road occurrence well-rounded pebbles of fresh olivine basalt are conspicuous. These accumulations are doubtless in part composed of redistributed pre-basaltic material but in part they are obviously post-basaltic. At Dalwood and near Melville bridge only redistributed grey billy was observed, and the pebbles and cobbles are smaller than those higher upstream.

The deposits have been to some extent used for road-metal, and in consequence small concentrations of rounded grey billy are apt to be found at subnormal or supranormal altitudes on quarry tracks or even on public roads ; for instance, several large boulders on the roadside on the Branxton-Stanhope road beyond the Elderslie bridge at 200 feet above the river are apparently discarded road material.

The loose gravels and boulders are at approximately the same level as the grey billy *in situ*, but at Jerrys Plains and elsewhere have accumulated up to at least 15 feet above the latter ; farther down the river they seem to extend below them. Thickness of the deposits is hard to determine because of the tendency to soil-creep ; that at Gosforth appears to be about 20 feet thick.

The terrace-deposits of grey billy and later gravels are, very roughly, 200 to 300 feet below the general level of the valley-plain in which the Lower Hunter is incised and a little over 100 feet above the present river level. They appear to follow approximately the meanderings of the river, though some of the more tortuous of these, winding as they do over siltic flood-plains, are plainly of more recent origin. It would seem that in earlier Tertiary time the floor of the meandering valley was but little above its present elevation, that its deposits were buried under basalt-flows, and that it rose little if at all during the subsequent Tertiary uplifts.

Basalt crowns the highlands at the source of the Upper Hunter and its tributaries, and the Liverpool Range basalts extend as far south as the latitude of Muswellbrook and to within 4 or 5 miles of the main river ; but the undulating country, in which the Lower Hunter is incised, is now, so far as is known, devoid of Tertiary basalt. Its removal during early Pliocene time was probably complete, partly because of the feeble response of the area to the forces of uplift and partly, as pointed out long ago by Taylor (1907*a*), because of the poor erosional resistance of the Permian beds in which the valley is largely excavated. It is pertinent to note that Dulhunty (1938) has mapped considerable remnants of Tertiary basalt in the valley of the Goulburn River, the chief tributary of the Lower Hunter, covering about one-third of its basin, and has reported the presence of grey billy at numerous places between its head and its junction with the Hunter at about 100 feet above the present valley floor.

Sussmilch (1940) rejected Raggatt's explanation of the grey billy as the result of alteration by basalt-flows, and equated it with siliceous duricrust such as appears in the far west of the State. His arguments were forced and unrealistic even in the light of what was known of duricrust at the time, and particularly so in view of the virtual certainty that the Lower Hunter grey billy is the equivalent of the silicified sub-basaltic deposits in the Goulburn River valley.

Northern Highlands (*New England*)

In New England Tertiary basalt covers a very much larger area than in any other division of the State and the sub-basaltic " drifts " have received considerable attention in the past because of their content of economic minerals. The deep leads in the north-west at Emmaville were reported on by David (1884, 1887*a*, 1887*b*), and those in the Inverell area by Carne (1911) and Cotton (1910), all of whom commented on the presence of grey billy as the result of silicification of sub-basaltic alluvium. In some instances an existing creek flows directly above its early Tertiary ancestor which, now hidden beneath basalt, may lie several hundred feet below the present surface ; or, again, the " deep lead " capped by basalt may crown the ridge forming the watershed between two parallel creeks. In Emmaville and to the west and north-west of it, where the Vegetable Creek lead and its branches were mined for stream-tin, there are many evidences of their presence in the shape of white clay, grey billy and patches of basalt.

The road from Inverell north to Ashford passes over basalt for much of the way, the " drift " underlying which in some places, as at Bukkulla, 21 miles from Inverell, is of fine iron-impregnated gravel. On the 3-mile descent of 600 feet from the lateritized plateau on the south to the Macintyre River at Inverell one may note a number of grey billy outcrops at different levels resting on granite bedrock and underlying basalt, evidently terrace-deposits.

From Glen Innes south to the vicinity of Armidale the Main Divide is composed mostly of Tertiary basalt, in places resting on alluvium. Some present-day valleys, like that of Beardy River, are clearly older than the basalt, which may form a considerable filling with an upper surface lower than the old granitic valley-walls. Other old rivers have been laterally displaced by basalt, and some of the basalt-capped spurs branching from the Main Divide have sub-basaltic deposits exposed on their flanks as, for example, some 5 miles along the road from Ben Lomond to Wandsworth, where grey billy underlies basalt at an altitude of about 4,075 feet ASL. Voisey (1942*b*) has mapped this and other occurrences of sub-basaltic deposits in southern New England and noted the frequency of grey billy among them ; and (1942*a*) has used grey billy as an aid in determining approximately the pre-basalt topography in the neighbourhood of the Main Divide between Glen Innes and Walcha.

David (1887*a*) reported on the country forming the Rocky River and Uralla goldfield. It seems that the earlier Tertiary basalt that covered the old valley deposits was reduced to scattered flat-topped remnants at between 3,500 and 3,600 feet by the early Pliocene ancestor of Rocky River ; this formed a wide valley-plain at about 200 feet lower, laying bare the pre-basalt auriferous deep-leads and revealing grey billy in several places. David found that the local miners used the term " white billy " to describe a very hard, dense rock cropping out around the margins of basalt sheets or laid bare by erosion, in places acting as a resistant covering to auriferous sands, and elsewhere forming a breccia. It contains some kaolin and is perhaps a silicified clay.

Many years ago on a rapid motor-trip from Walcha, along the Oxley Highway to Tia and thence to Nowendoc across a west-east spur of the Main Divide at 4,300 feet, much Tertiary basalt was encountered particularly at the higher levels, where it was at least 300 feet thick. The pre-basalt surface must have been of considerable relief, bedrock of phyllite and schist invaded by gneissic granite being in places at altitudes of nearly 4,100 feet ASL, and locally overtopping the basalt nearby. The basalt seemed to rest mostly on bedrock but occasionally on alluvial deposits 30 or 40 feet thick. Grey billy was noted on the Oxley Highway six miles east of Walcha at 3,300 feet and at a point 21 miles north of Nowendoc at about 3,900 feet ASL, associated with basalt and resting on schists. Some of the metamorphic bedrock was locally silicified, the alteration being possibly related to the basalt eruptions.

On the western slopes of the New England plateau a few miles north of Barraba the east-west Nandewar Range is formed of Tertiary basalt-flows overlying a deposit of diatomaceous earth and with interflow beds of leached sand and clay.

In various parts of New England there are accumulations of uncemented gravels in upland valleys as, for example, a few miles east of Armidale on the road to Hillgrove and near the Oxley Highway some 13 miles from Walcha along the Apsley River just above the Apsley Falls. These deposits are probably post-basalt and are above the limits of rejuvenation caused by the Kosciusko uplift; they are provisionally regarded as earlier-Pliocene.

On the west, some 15 miles north of Narrabri on the way to Killarney Gap in the Nandewar Mts., the road traverses a wide boulder-fan of which redistributed grey billy is a prominent constituent; with it are boulders, increasing in size towards their source, of teschenite, basalt and trachyte brought down by creeks from the heights of the volcanic Nandewar Mts., and probably still accumulating.

Grey Billy in Other States

So far as I know, the grey billy association is found only in the four eastern States.

According to Murray (1887) Tertiary sands and gravels, in many instances silicified, are commonly associated with the Older basalts of Victoria, particularly in the east; some of these form the summits of plateaux and plateau-remnants rising to 5,000 feet ASL, e.g. the Dargo and Bogong High Plains, Mt. Useful, etc., while others are at medium elevations around the flanks of the main highlands at Glen Maggie, Tanjil, Russell Creek and elsewhere in Gippsland. More recently Gill (1942) has described from the Lilydale district silicified sands and gravels, whitish clays and lignites underlying the Older basalts.

From south-eastern Queensland in the mature Brisbane River valley between Brisbane and Ipswich Jones (1926) has described and illustrated blocks of quartzite up to 15 feet long enclosing many angular fragments of siliceous rock. The blocks are embedded and partially buried in uncemented heteropsephitic gravels and boulder-beds which Jones included in his Redbank Series, though Whitehouse later (1940) queried the placement.

Under the guidance of the late Professor W. H. Bryan, I had an opportunity of examining the principal occurrence at Sherwood close to the meandering Oxley Creek, a tributary of the Brisbane River. A remnant of the basalt contemporaneous in the Redbank Series crops out a mile away, and field examination leads one to conclude with some confidence that the quartzite blocks are relics of a sheet of grey billy related to basalt, which has been locally eroded away. Exposure of the sheet and its disruption and redistribution by river action, probably in early Pliocene time, were followed by partial burial in river detritus.

Jones also records limestones of the Redbank Series in Queen's Park, Ipswich, which are believed to have been partially silicified by overlying basalt; Tertiary limestone some 16 miles south of Ipswich has been similarly altered.

Richards (1916, p. 115) found deposits of diatomaceous earth interbedded among the Tertiary basalt flows of south-eastern Queensland, and I have had the opportunity of seeing one of these beds, between Canungra and Beechmont, now partially converted into common opal, apparently under the influence of the overlying basalt flow. Skeats (1914) described common opal from beds associated with Tertiary basalt at Tweed Heads on the New South Wales border.

In the valley of the Logan River east of Beaudesert the late Mr. L. C. Ball, then Chief Government Geologist of Queensland, showed me blocks, up to 2 feet thick and 6 feet in diameter, of grey billy virtually *in situ* some 20 feet above the present river, apparently related to a former valley-filling basalt of which remnants are visible on the adjacent plateau. This basalt is probably Lower Miocene, like that of Beechmont and Toowoomba (Webb *et al.*, 1967).

The grey billy in the Clermont-Anakie area described by Dunstan and mentioned above, is related to basalt whose geological age is uncertain, but whose mode of occurrence and relation to the topography suggest an earlier-Tertiary rather than a Pliocene age.

Morgan (1968) has reported flows of basalt from the Cooktown area and listed " billy " among the Kainozoic deposits, but gives no indication of its relation to the basalts.

From the West Coast of Tasmania 5 miles east of Granville Harbour, Waterhouse (1914) described a succession of horizontally-bedded fluviatile quartz-conglomerates, grits and sandstones, at least 100 feet thick, containing detrital tourmaline and topaz and chips of silicified wood, and partially overlain by Tertiary basalt. Locally unconsolidated, they have been in places cemented by silica (quartz and chalcedony), thought to have resulted from decomposition of the basalt. Waterhouse's careful description leaves no doubt that the silicified rock is grey billy. No precise dating of the basalt has been made, but from physiographic considerations it may be older Tertiary.

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